AD-A187 642 THE STRUCTURE AND CONTROL OF THREE-DIMENSIONAL SHOCK 1/1
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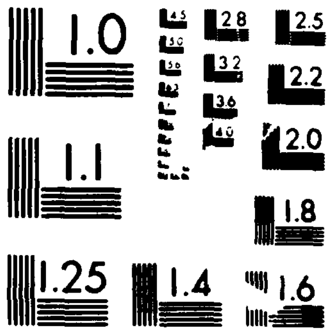

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A review of the work completed during the first year of research on the subject contract is presented. Papers and publications generated, staff, and students involved in the research are noted, along with a brief description of the on-going program. Significant results have been obtained in defining the structure of the three-dimensional shock wave turbulent boundary layer interaction by combining detailed experiments with coordinated major computational programs.

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I. CONTRACT WORK STATEMENT

The overall work statement of the subject contract was to investigate new control concepts for three-dimensional shock wave turbulent boundary layer interactions at Mach 3 by carrying out research on the following four tasks:

1) Use the established flowfield generated by a 20° sharp fin to investigate the effectiveness of several control concepts on the interaction and the flow downstream.

2) Establish the key flowfield features of flows on wedges and cones so that control concepts can be developed for these geometries.

3) Generate surface heat transfer data to better define the interactions and provide another critical test of computational sensitivity to turbulence modeling assumptions (AFWAL support).

4) Interact closely with computational efforts for validation, limits, and when possible, flow structural details, to provide the basis for extended studies of control concepts.

II. WORK COMPLETED DURING THE FIRST YEAR

1) Published papers and presentations

The completed studies have been presented at national and international meetings and are available in printed form as noted in Appendix A. The published results are available as one IUTAM paper, one AIAA Journal paper, and four AIAA preprints, several of which have been submitted for publication in the Journal.

2) Brief review of completed studies

a) The paper by Bogdonoff, entitled "Observation of the Three-Dimensional "Separation" in Shock Wave Turbulent Boundary Layer Interactions," was presented at the 1986 IUTAM Symposium on Boundary Layer Separation, held at University

College, London, in August 1986. The paper details a set of observations obtained during previous studies under OSR support of two- and three-dimensional shock wave turbulent boundary layer interactions. Comparison of the details of specific two and highly swept three-dimensional shock wave turbulent boundary layer interactions resulted in the following observations:

1) three-dimensional flows are radically different than the "classical" two-dimensional flows,

2) the scale, pressure gradients, unsteadiness, and computability are quite different,

3) the designation of "separation" in three dimensions is not realistic, and

4) a concept of vorticity rearrangement is proposed to describe the physics of the interactions in three dimensions.

b) The Journal article by Tan, Tran and Bogdonoff, entitled "Wall Pressure Fluctuations in a Three-Dimensional Shock-Wave/Turbulent Boundary Interaction," Reference B of Appendix A, and the AIAA preprint by Tran and Bogdonoff, entitled "A Study of Unsteadiness of Shock Wave/Turbulent Boundary Layer Interactions from Fluctuating Wall Pressure Measurements," Reference C of Appendix A, detailed our latest studies of the unsteadiness of shock wave turbulent boundary layer interactions by using multiple wall static pressure measurements. This unique series of measurements provides, for the first time, some direct evidence of the steadiness of these three-dimensional flows, evaluates the effect of shock pressure ratio, and permits a comparison of the three-dimensional and two-dimensional cases. Some typical results are shown in Figures

1a and 1b. Figure 1a shows the effect of varying shock pressure ratio while Figure 1b shows the effect of varying the shock generator geometry but keeping the shock pressure ratio constant. In both cases, the rms value is non-dimensionalized by the local mean value, which varies continuously through the interaction. The appearance of a decrease in the fluctuations in the downstream region of the interaction should be noted as a percentage fluctuation of a local value which has increased from the initial values. The characteristic shapes of the fluctuating pressures are well established. There is a strong peak in the initial part of the interaction (between the mean upstream influence line and the line of convergence), an approximately uniform region until the location of the theoretical shock wave, and then a slow decrease, with the final values approaching those of the upstream boundary layer (when non-dimensionalized by the local values). It is important to note that the general fluctuating pressure level is about half of the two-dimensional case for the same strength shock wave, the general shape of the distribution is similar to the two-dimensional case, and that the flows are far from steady. The source of the disturbing function and the mechanism of the interaction has not been defined from the present experiments.

c) Shapey and Bogdonoff in the paper entitled, "Three-Dimensional Shock Wave/Turbulent Boundary Layer Interaction for a 20° Sharp Fin at Mach 3," Reference D of Appendix A, was a continuation of a detailed study of three-dimensional shock wave boundary layer interactions. Detailed flowfield surveys, such as Figure 2 and 3, provided the information to construct flowfield models and to interact with the computation of Knight et al. (presented last year at the AIAA). The primary emphasis over the past couple of years has been on the sharp fin and the swept compression corner. The Shapey-Bogdonoff paper continued this detailed comparison of computation and experiment for the sharp

fin. The results shown in Figures 4 and 5 indicates the considerable differences in the computation and the experiments with regards to surface flow conditions. The paper by Knight, et.al. [Reference E of Appendix A, entitled "Supersonic Turbulent Flow Past a 3-D Swept Compression Corner at Mach 3], made the detailed comparison with the swept compression corner work of Ruderich, Mao and Bogdonoff. It showed that the same general structure of the flowfield was found for both the sharp fin and the swept compression corner, that a significant part of the outer flow appeared to be inviscid-rotational, and that the experiments and computations differed significantly close to the floor.

d) The paper by Kimmel and Bogdonoff, entitled "A Comparative Experimental Investigation of Shock/Turbulent Boundary Layer Interactions Produced by Three Shock Generators," extended the studies of variable strength shock waves generated by the sharp fin to explore the premise that the initial part of the interaction was determined by the shock strength and orientation, independent of the shock generator configuration. A swept corner, sharp fin, and a semi-cone model were designed to generate the same strength and orientation shock wave traced on the floor. The results, shown in Figure 6a and 6b, clearly indicate that the initial part of the interaction is similar for all three shock generators and the lower part of all three flows are quite similar close to the shock generator. The differences in the generated shock shape in the outer flow makes significant difference in this part of the flowfield. It is clear that the general flow structure is primarily determined by the shock strength, with only secondary effects close to the body being different for the different generators.

3) Completed Experimental Studies

One experimental study was completed but the analysis of the results are still underway. Wang, Mao, and Bogdonoff examined a problem fundamental to all

three-dimensional interactions, the effect of varying boundary layer characteristics in the lateral direction. For highly swept interactions, the boundary layer far from the apex is usually considerably thicker than that at the apex. Although the general concept is that the flowfield scales with boundary layer thickness, there has not been a definitive test which supports or refutes this hypothesis. The use of the average boundary layer thickness along the interaction, the boundary layer thickness at the apex, or the local boundary layer thickness at each point along the interaction has not been clearly defined. Wang, et al. set out to study this effect by using a swept plate geometry to get approximately constant boundary layer thickness along the interaction for a swept compression corner, Location A of Figure 7. A similar but mirror image geometry was located at Location B for a second test. The boundary layer thickness at the apex of both models was the same, but clearly the distribution of boundary layer thickness along the interaction was quite different for the model at location A and at location B. A full series of pressure distributions and surface flow visualization data were obtained, but the analysis has not yet been completed because of Mrs. Mao's departure.

III. FACULTY, STAFF AND STUDENTS INVOLVED IN THE PROGRAM

Professor Bogdonoff was the primary faculty involved in the program with some inputs from Professor Smits. The students involved in the program were:

T. Tran, Ph.D. - July 1981 thru August 1986
R. Kimmel, Ph.D. - July 1982 thru October 1986
B. Shapey, MSE - September 1985 thru October 1986
D. Trevas, MSE - July 1986 thru June 1987
A. Ketchum, MSE - September 1986 thru present
S. Toby, MSE - September 1986 thru present

Dr. Ruderich was deeply involved in the program until he left in September of

1986, at which time Dr. Watmuff joined the program (25% time) working with Prof. Bogdonoff. Mrs. M.-F. Mao, a visiting research engineer from Beijing, China, was involved with the research from October 1985 thru January 1987.

IV. ON-GOING STUDIES

1) The Low Turbulence Variable Geometry Tunnel (LTVG) is being assembled for calibration in preparation for the tests of the two- and three-dimensional configurations to compare results with that of the high Reynolds number supersonic tunnel.

2) Static pressure surveys, using a new small static pressure probe programmed from the yaw surveys, are underway for the 20° fin and the 24-40 wedge, Figure 8. These static pressure surveys provide new information on the flowfield structure and, with the total head surveys, permit the calculation of the local Mach number profiles for direct comparison with the computations, Figure 9.

3) The first of the control studies are being carried out with detailed static pressure surveys and surface flow visualization being carried out for two configurations, the 20° sharp fin with variable gap between the fin and the tunnel wall, Figure 10a, and the cranked fin geometry of Figure 10b.

4) Detailed studies of the optimum design for the models to test highly swept interaction crossing and termination at the wall have been underway for some time with final model design nearing completion, Figure 11.

5) Work continues on the development of small high frequency heat transfer gauges to be used in the study of heat transfer and skin friction under three-dimensional shock wave boundary layer interactions.

APPENDIX A:

Published Papers & Presentations

A) Bogdonoff, S. M., "Observation of the Three-Dimensional "Separation" in Shock Wave Turbulent Boundary Layer Interactions," Presented at the 1986 IUTAM Symposium on Boundary-Layer Separation, University College, London, August 1986.

B) Tan, D.K.M., Tran, T. T. and Bogdonoff, S. M., "Wall Pressure Fluctuations in a Three-Dimensional Shock-Wave/Turbulent Boundary Interaction," AIAA Journal, Vol. 25, No. 1, January 1987, Pg.14.

C) Tran, T. T. and Bogdonoff, S. M., " Study of Unsteadiness of Shock Wave/Turbulent Boundary Layer Interactions From Fluctuating Wall Pressure Measurements," AIAA 25th Aerospace Sciences Meeting, Paper #87-0552, Reno, Nevada, January 12-15, 1987.

D) Shapey, B. and Bogdonoff, S. M., "Three-Dimensional Shock Wave/Turbulent Boundary Layer Interaction for a 20° Sharp Fin at Mach 3," AIAA 25th Aerospace Sciences Meeting, Paper #87-0554, Reno, Nevada, January 12-15, 1987.

E) Knight, D., Horstman, C. C., Ruderich, R., Mao, M.-F. and Bogdonoff, S., "Supersonic Turbulent Flow Past a 3-D Swept Compression Corner at Mach 3," AIAA 25th Aerospace Sciences Meeting, Paper #87-0551, Reno, Nevada, January 12-15, 1987.

F) Kimmel, R. L. and Bogdonoff, S. M., "A Comparative Experimental Investigation of Shock/Turbulent Boundary Layer Interactions Produced by Three Shock Generators," AIAA 19th Fluid Dynamics, Plasma Dynamics and Lasers Conference, Paper #87-1366, Honolulu, Hawaii, June 7-10, 1987.

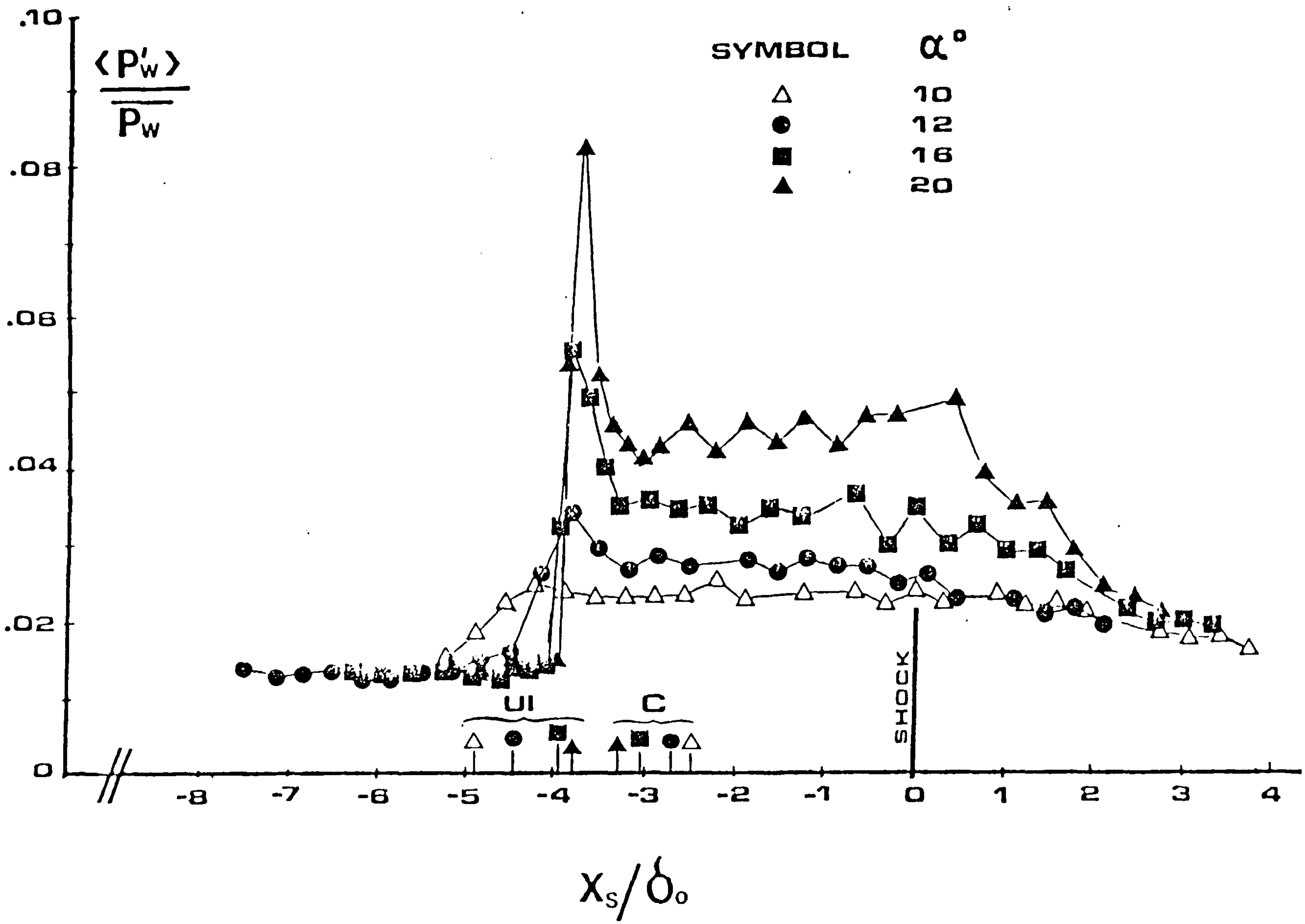

Figure 1a. Distribution of rms of wall pressure fluctuation for fin interactions. Normalized by local mean pressure.

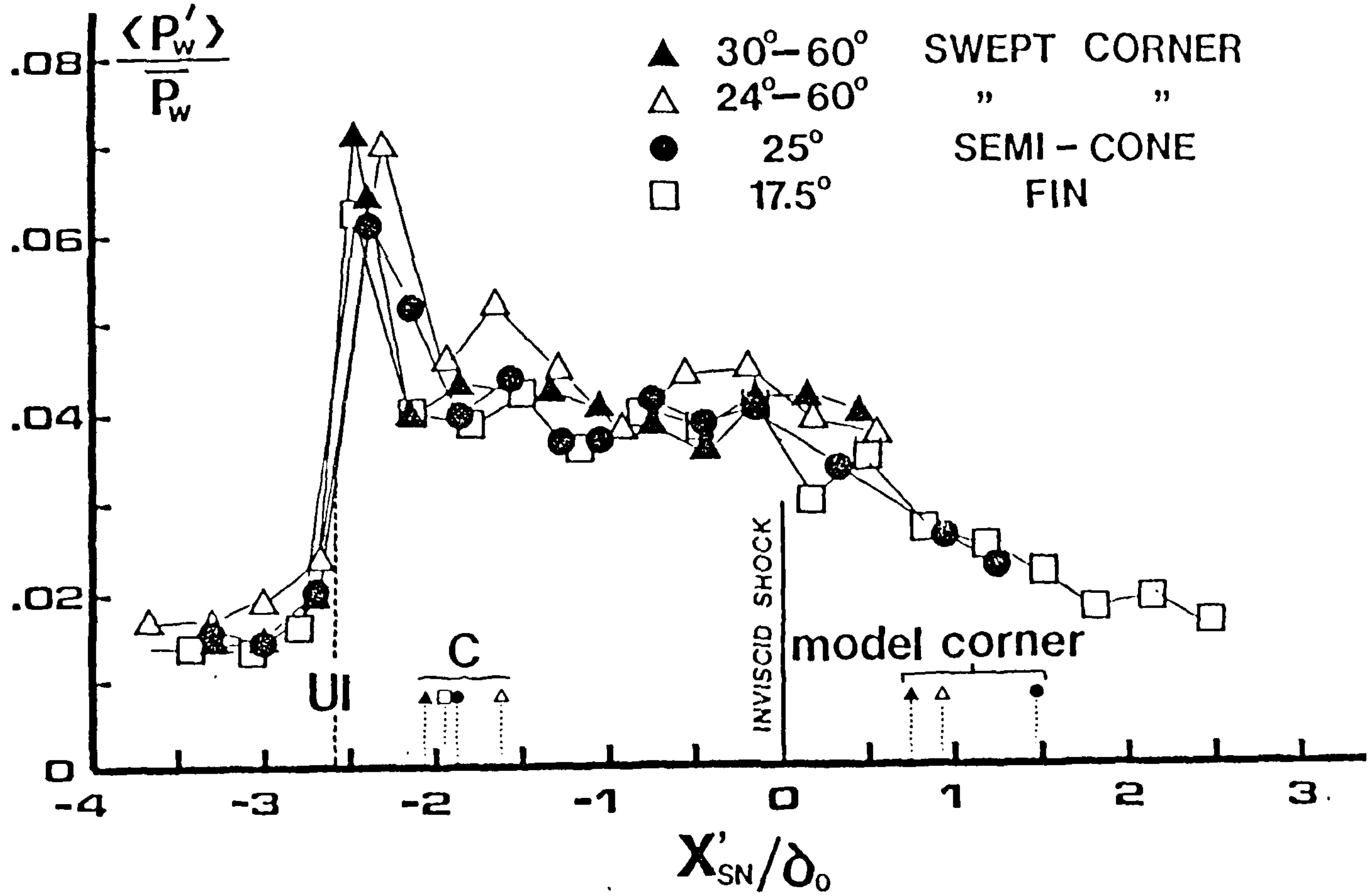

Figure 1b. Distribution of rms of wall pressure fluctuation for different shock generators. Normalized by local mean pressure. (Data from Kimmel[16] and Ruderich and Mao[17].)

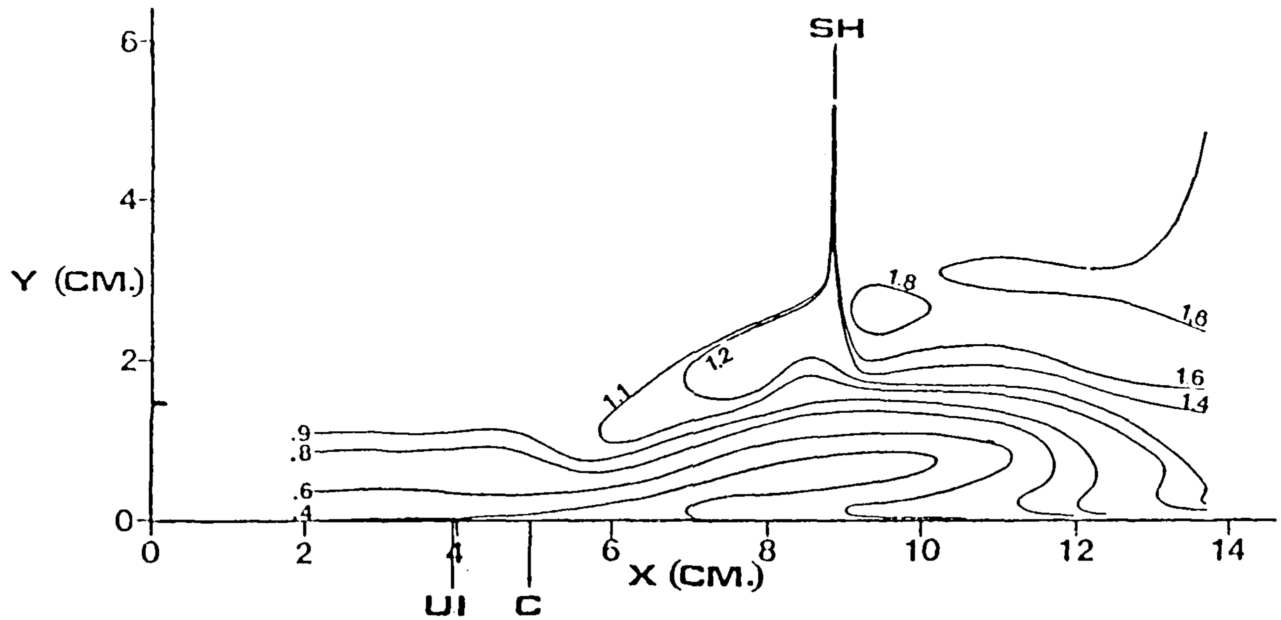

Figure 2. Normalized Total Head Contours.

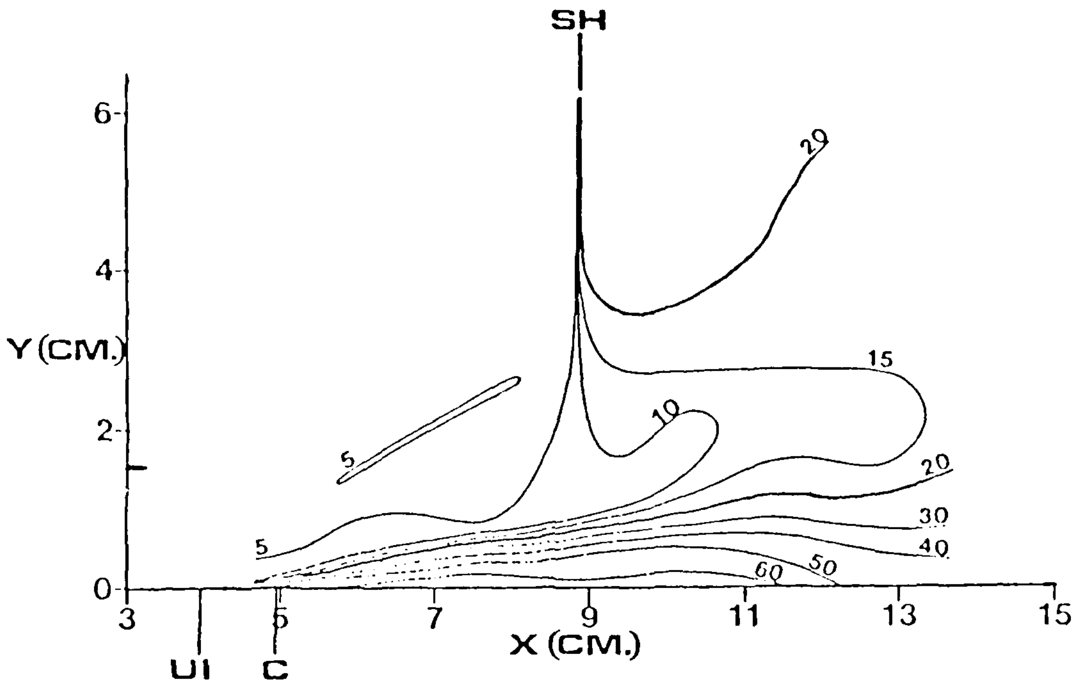

Figure 3. Yaw Angle Contours.

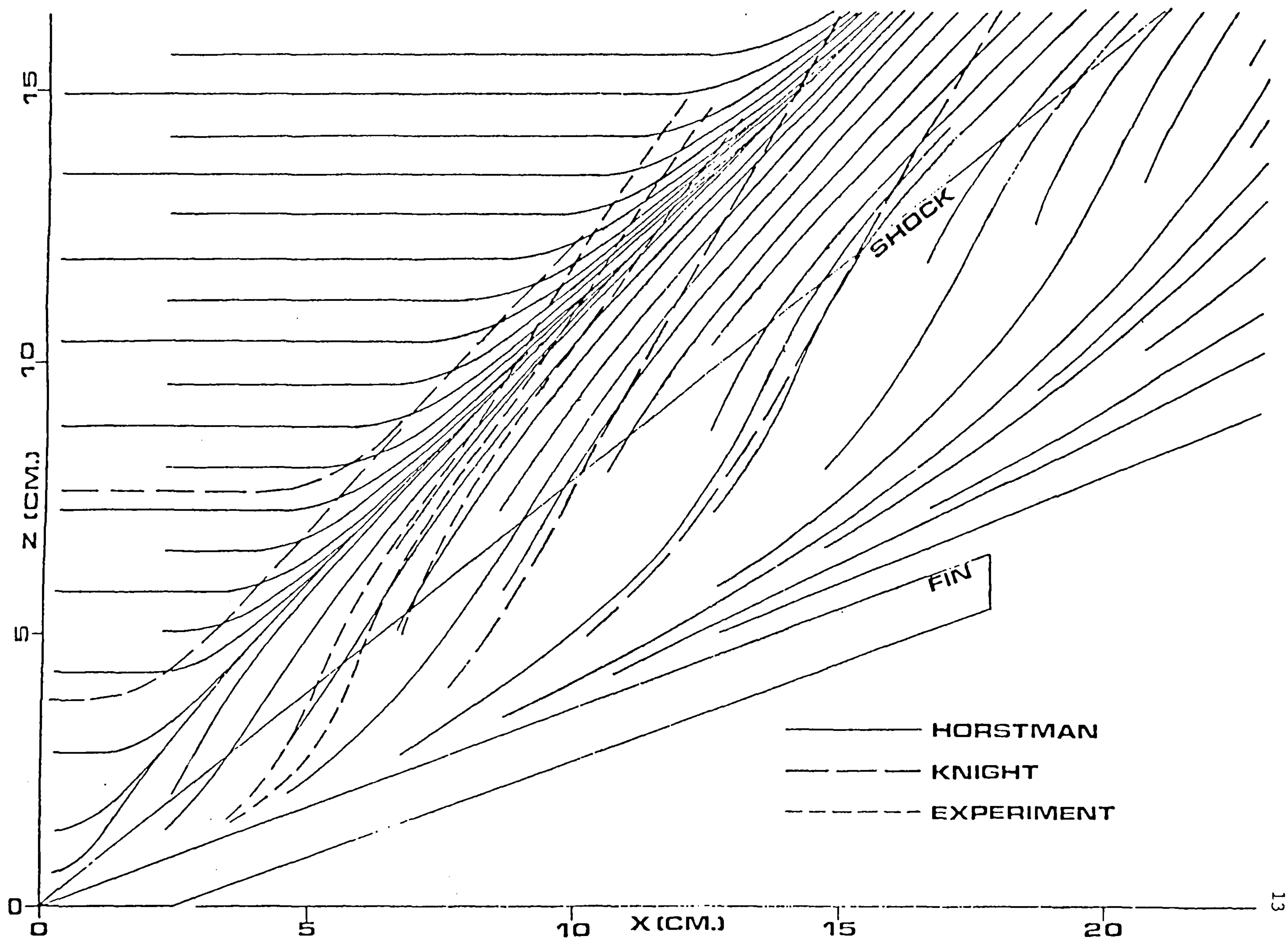

Figure 4. Computed and Measured Surface Streaklines.

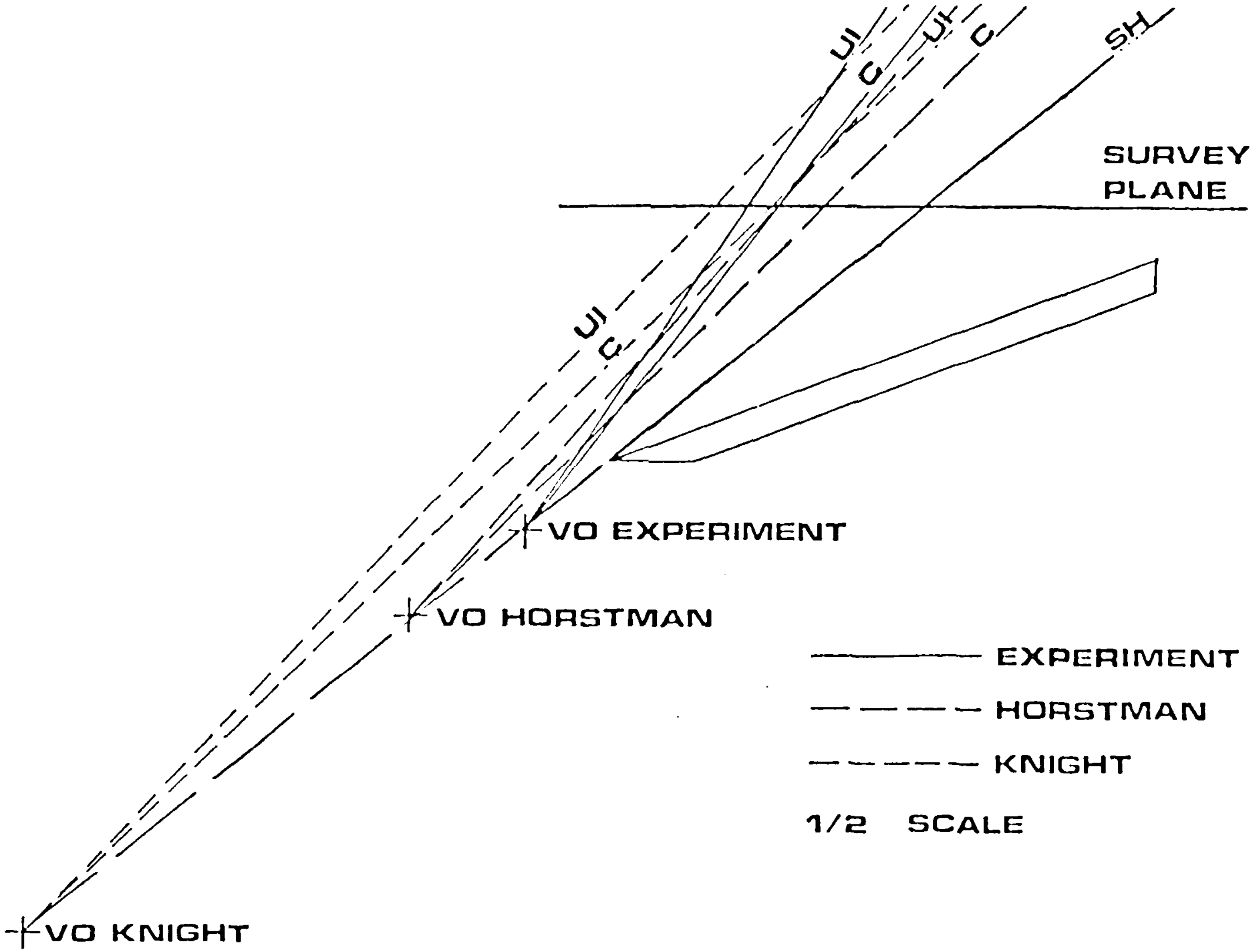

Figure 5. Experimental/Computed Upstream Influence, Coalescence, Virtual Origin.

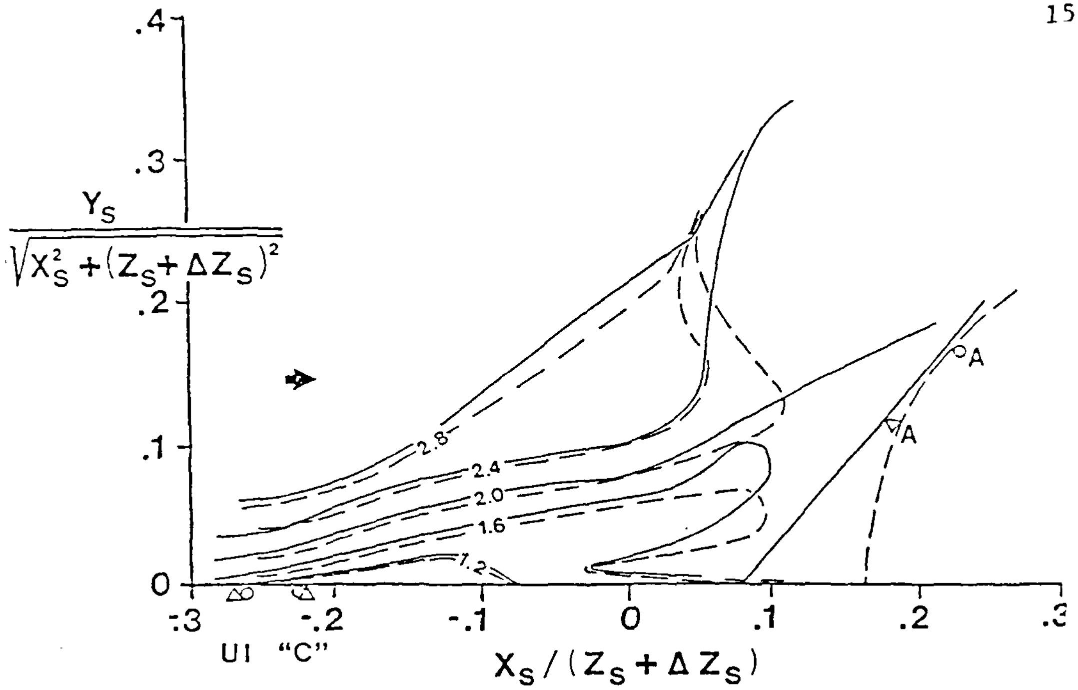

Figure 6a: $\alpha=30°$, $\lambda=60°$ Swept corner (solid) and $\gamma=25°$ semicone (dashed) Mach contours.

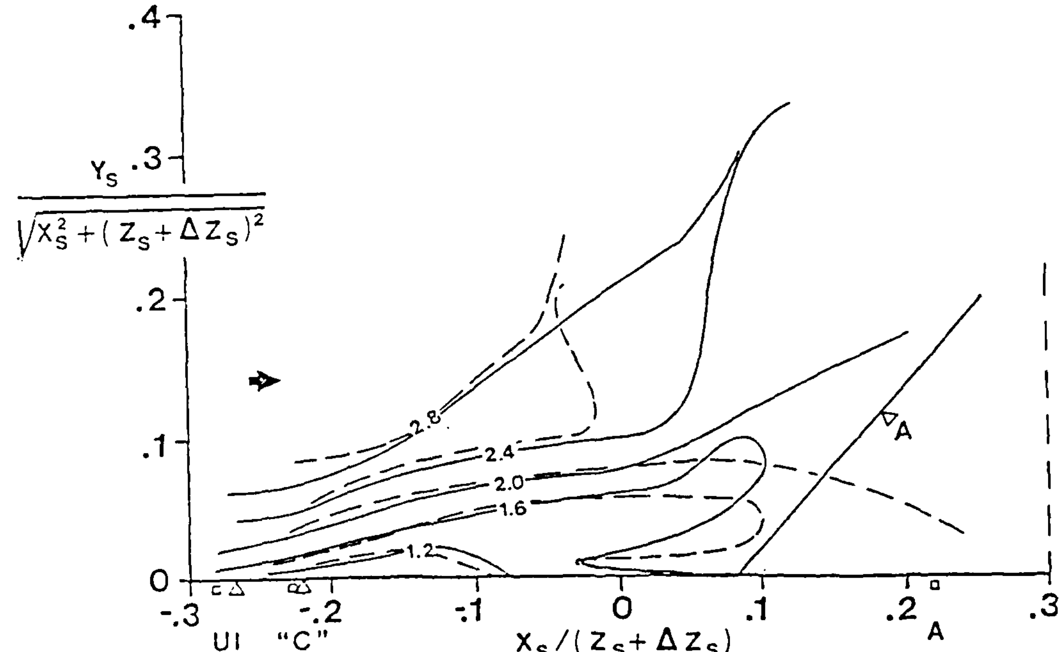

Figure 6b: $\alpha=30°$, $\lambda=60°$ Swept corner (solid) and $\alpha=17.5°$ fin (dashed) Mach contours.

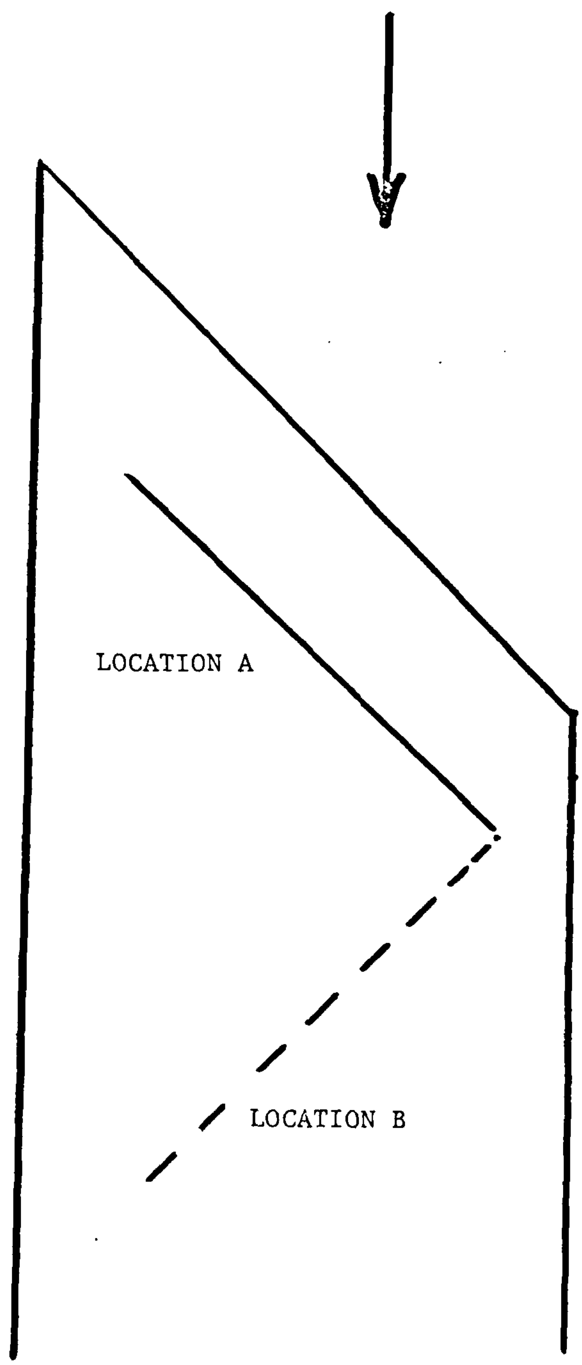

Figure 7. Plate and Model Geometry for Wang, et al.

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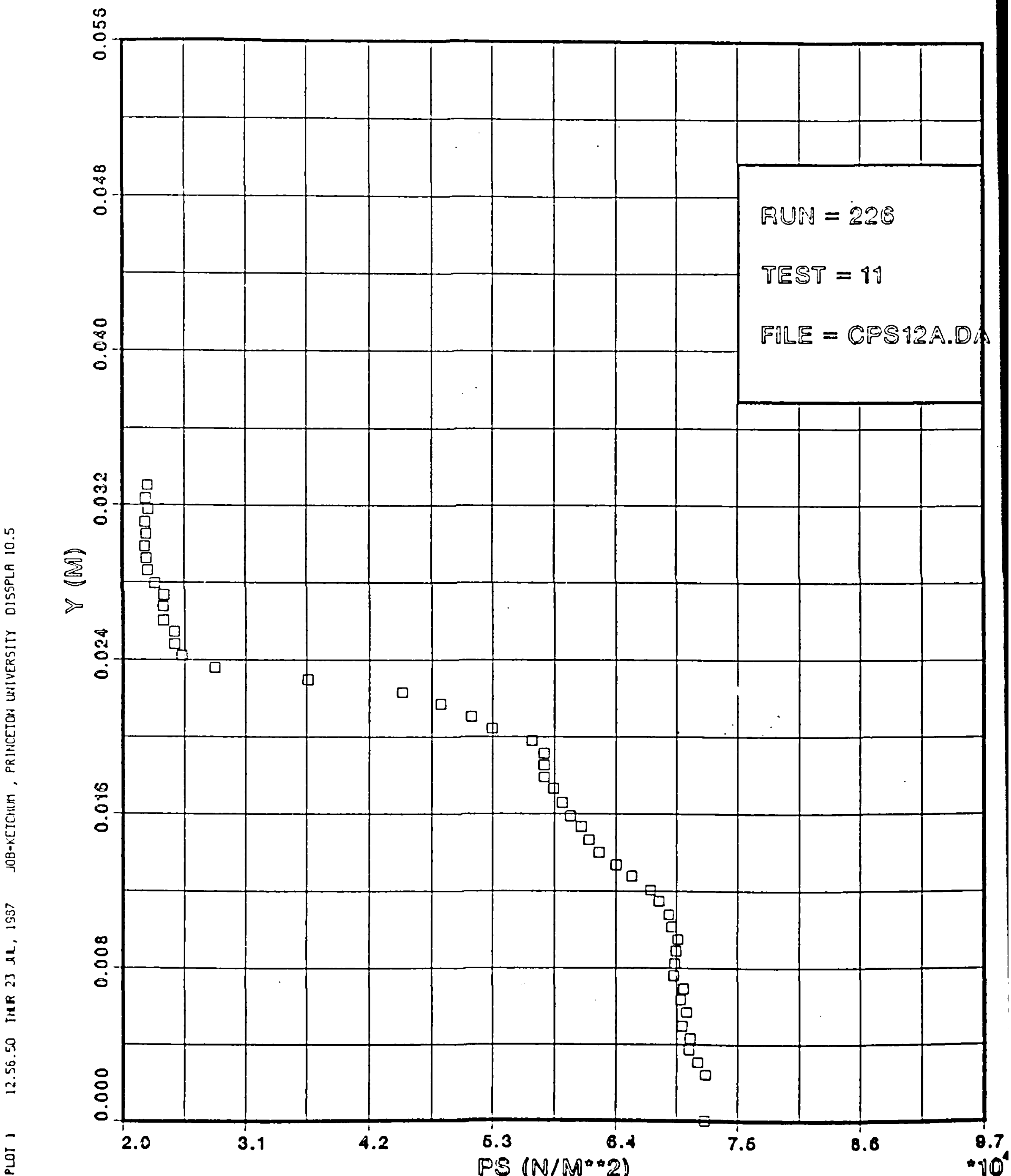


Figure 8. Example of the Static Pressure Distribution Through a Swept Wedge Flowfield.

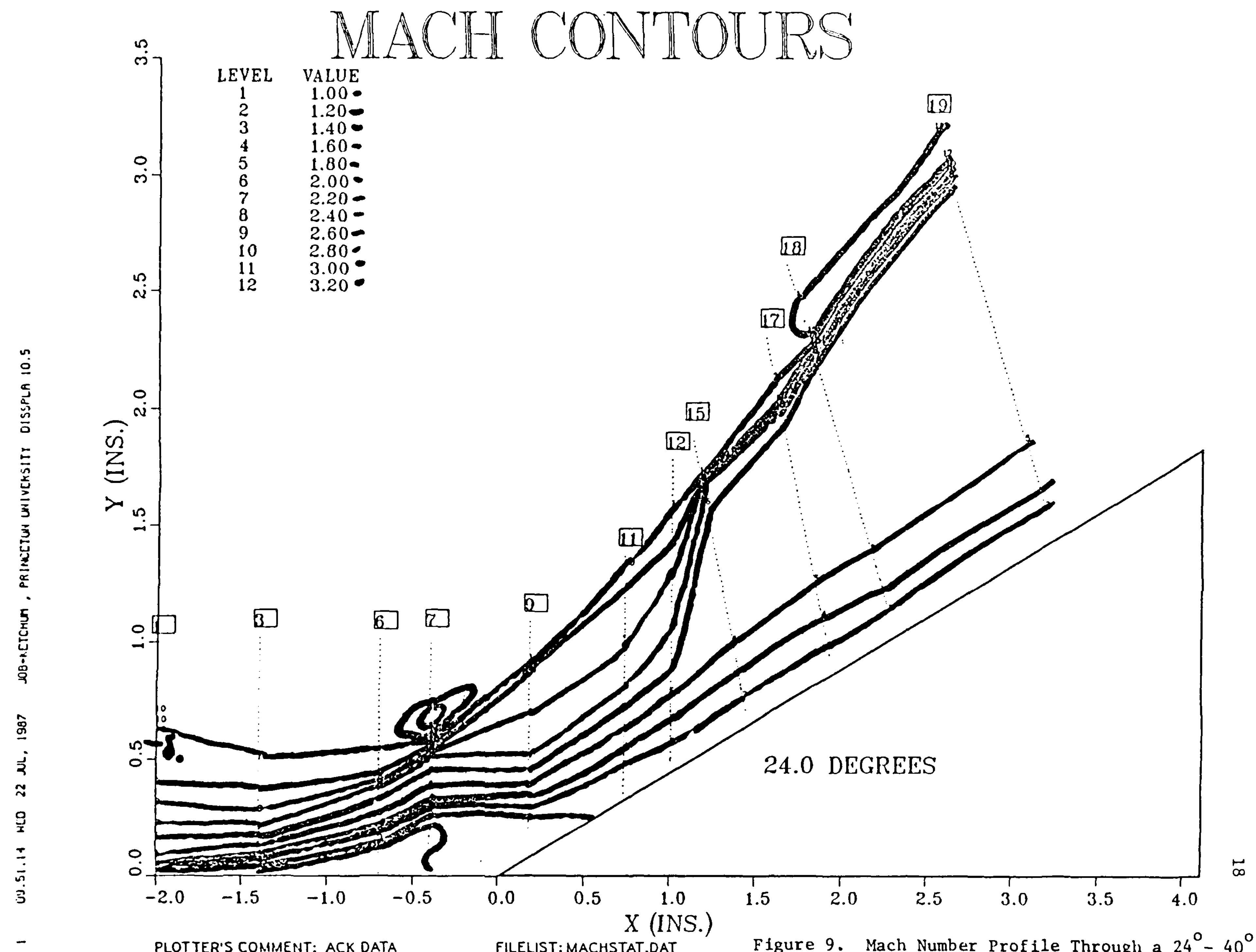
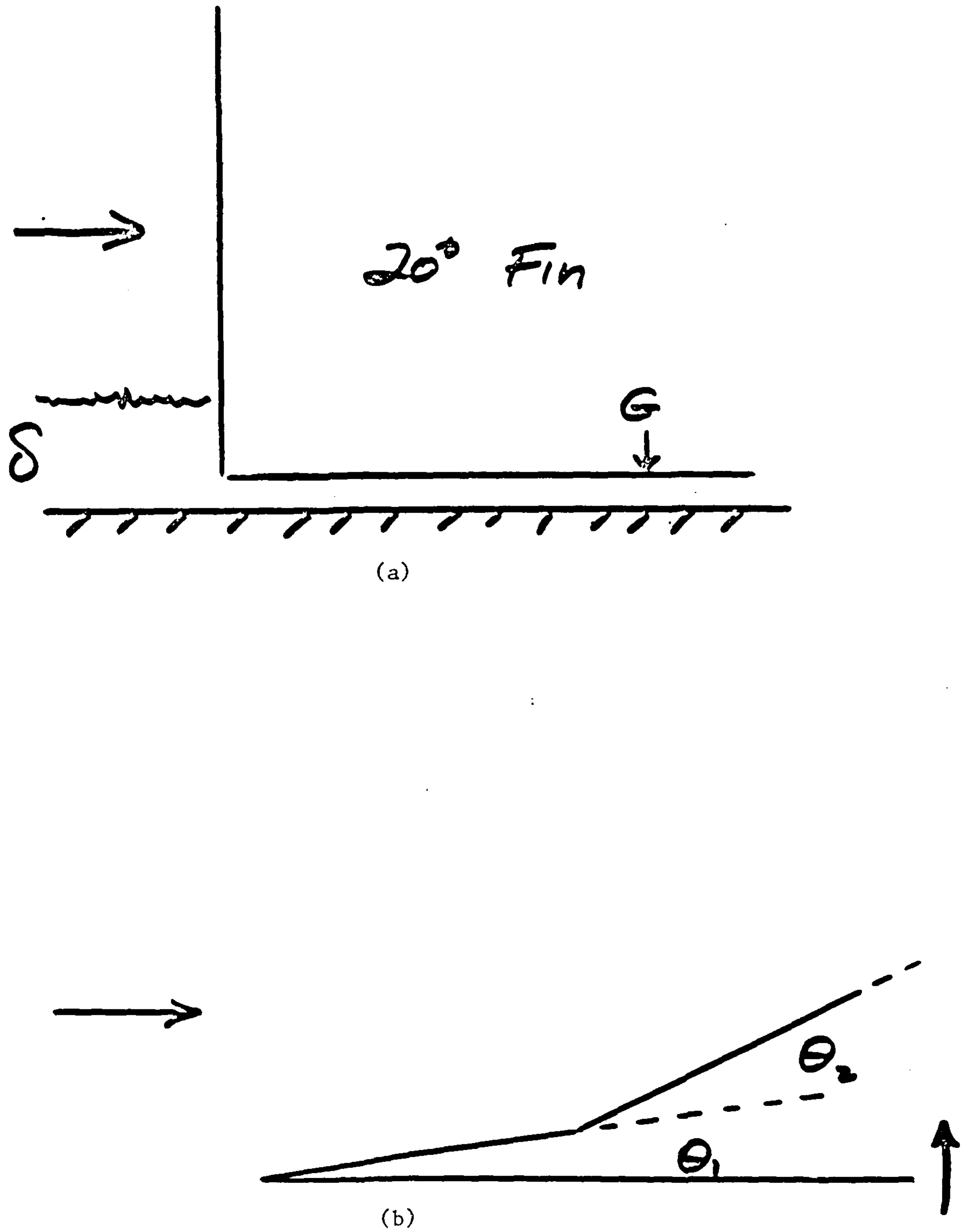


Figure 9. Mach Number Profile Through a 24° - 40°



(a)

(b)

Figure 10. Initial Control Configurations.

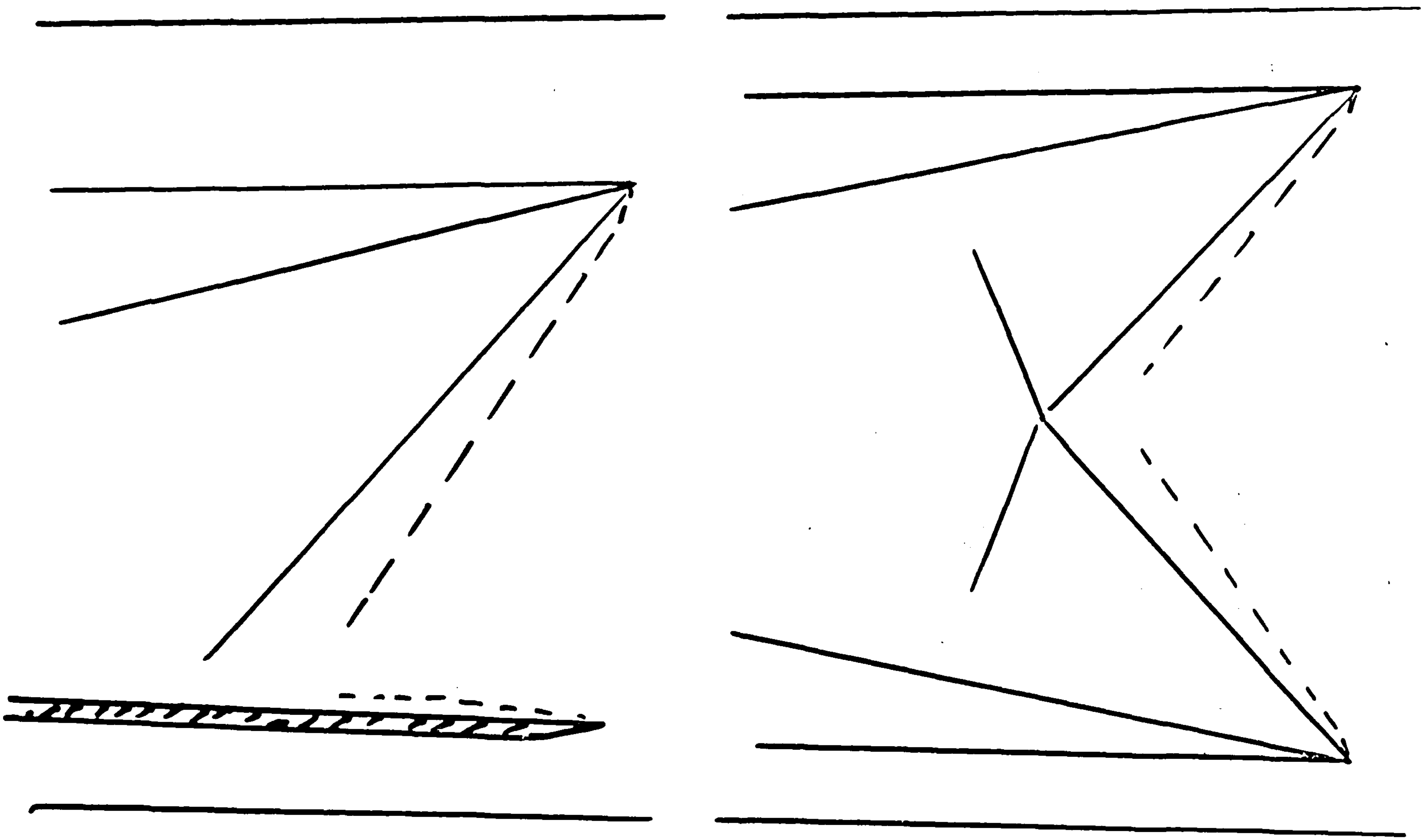


Figure 11. Test Configurations for Interaction Crossings and Termination.

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